Real-Time Communication Support for Over-water Wireless Multi-hop Networks

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Extended Abstract

Motivation. The prospect scenario for wireless communications and networking technologies in aquatic environments is nowadays promising. The growing interest around this subject in the last decades has recently been accelerated due to the more powerful capabilities of a number of sensing, control and communication devices. Moored, fixed, drifting, and vehicular nodes form now a rich ecosystem of autonomous embedded systems potentially connected in a multi-hop (and over-water) fashion, which demand innovative solutions to satisfy the ever-increasing requirements of reliability, bandwidth, latency and cost [1]. The efforts in this direction, mostly as a result of the push from the Internet-of-Thing (IoT) and related communication paradigms, are now at an early stage, and thus still pose significant, technical and research challenges, especially from the perspective of communication and nerworking for applications involving real-time and/or multimedia networking traffic.

Research Challenges. In effect, many issues arise when wireless communication occurs above water [2]. The different radio propagation behaviour, when compared to the over-land case, prevent a direct application of most general-purpose solutions. The radio signal reflections are much stronger, and this may lead to much more severe interference on the link quality. The natural water movements (such as tides and waves), among other distinctive phenomena, increase the prior difficulties and thus add extra considerations to the already challenging scenario. The mitigation of these factors by means of a careful design of link parameters (e.g., distance, height, polarization), as well as with diversity (and non-diversity) strategies is a well-studied topic in communications; but, mostly focused on the long-range. The case of short and medium-range distances with antennas at a few meters above surface still shows non-conclusive ideas, e.g., in terms of the most suitable propagation model to guide the network design labour. Moreover, the impact of tides (and waves) cycles in this more restricted settings show little or null effort in the literature. The relevant techniques that, e.g., have been proposed to mitigate the so-called tidal fading [3], although effective on the long-range, do not show clear applicability when water level fluctuations are in the order of the antenna height, and/or the link distances are relatively short. The general situation is further aggravated if extended to multi-hop networks, where the effect of water-level variations over-the-time can significantly degrade the connectivity of several links simultaneously; an issue that still deserves further studies.

Related Work. In the literature, different strategies at physical, link and network levels have been proposed to cope with problems of a similar kind. In maritime communications, e.g., dynamic/adaptive routing schemes helping to undertake the intermittent ship-to-ship connectivity issues due to varying sea-state levels have extensively been explored (e.g., [4]). At the link level, protocol adaptations, e.g., to enable more reliable and/or predictable packet-level behaviour have also been considered. Likewise, physical layer techniques such as multiple antenna systems and beamforming have been explored too. These works, as well as several others in different (but related) fields, although do not show straightforward match with our primary research direction, can act as a fruitful source of inspiration, and thus represent an important starting point.

Research Proposal. In this research, we focus on the communication and networking aspects of over-water multi-hop networks aiming at support real-time and/or multimedia (audio/video) traffic using IEEE 802.11 (WiFi) commodity technologies. Special attention is devoted to the impact of cyclic water-level variations (such as tides and waves) on the overall network performance, and how an integrated approach to (i) network design, (ii) protocol adaptation and (iii) routing can contribute to mitigating such an issue.

Fig. 1 graphically summarizes our research proposal.

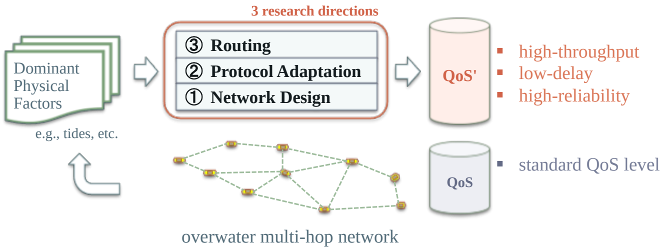

Fig. 1 An schematic illustration of the research approach taken.

A. Network Design

This research line considers both, the geometrical basis of the two-ray propagation model [5] and the foreseeable nature of water movements as the key inputs to provide better strategies to link design and network planning. To this aim, our first step is to experimentally assess the over-water channel, particularly at near-shore/low-altitude (marine or freshwater) areas affected by noticeable over-time water-level variations. Along this line, our preliminary works in [6,7] show a considerable consistency between RSSI packet-based measurements (using WiFi COTS) and the theoretical predictions of the two-ray model. These works, strengthen our initial intuitions in [8,9] that suggest the two-ray as an effective method to estimate the large-scale fading in the presence of strong surface reflections. Thus, as convenient to guide the design of over-water network deployments. The next steps in this direction consider further experiments using both, a broader distance/height granularity and different antenna polarization. Once properly assessed the channel, we target to provide better network planning strategies based on discrete optimization techniques (closed-form and/or heuristic) that maximize/minimize a given QoS metric, while minimizing antenna height or another relevant parameter.

B. Protocol Adaptation

This line of proposes the family of reconfigurable-and-adaptive TDMA overlay protocols, also known as RA-TDMA [10-12], as the primary source of related work to build upon. Here, we aim at extending them by mechanisms driven/aware of the water-level cycles, while oriented to improve the performance of real-time/multimedia applications. The RA-TDMA is a prior work in our group, which have shown promising results in fields such as teams of mobile robots [10], aerial multi-hop networks [11], and vehicular platoons [12]. We expect to leverage on this research and further explore the extension to mesh networks, a line of work still open. The performance evaluation of the propose mechanisms is expected to be done with OMNeT++/INET framework while incorporating the tides/waves features to the simulator.

C. Routing

This research line conceives the development of novel methods for proactive/reactive routing, e.g., route-selection, forwarding, that adaptively respond to network topology dynamics. The end goal is to improve some overall QoS metric, regardless of the impact of water-level changes. We refer to [4] as a relevant work on this subject, providing some initial intuitions for the water-level dynamics mitigation in over-water multi-hop networks. Likewise, we refer to the work in [13], as with prior/promising insights for multi-hop routing on TDMA dynamic networks. The evaluation of these methods (as well as those in the previous direction), from the real-time network perspective, is expected to be done by means of analyses of the worst-case end-to-end delays and schedulability, using the approach described in [14,15].

D. Conclusion and Future Work

This research envisions future reliable and real-time network scenarios in coastal areas, where ubiquitous and heterogeneous nodes communicate mostly above water. In this respect, this paper summarizes the main research lines, key insights and prior research efforts done so far.

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References

[1] A. Zolich, D. Palma, K. Kansanen, K. Fjørtoft, J. Sousa, K. H. Johansson, Y. Jiang, H. Dong, and T. A. Johansen, “Survey on communication and networks for autonomous marine systems,” Journal of Intelligent & Robotic Systems, vol. 95, no. 3-4, pp. 789–813, 2019

[2] J. Wang, H. Zhou, Y. Li, Q. Sun, Y. Wu, S. Jin, T. QS Quek, and C. Xu. Wireless channel models for maritime communications. IEEE Access, 6: 68070–68088, 2018.

[3] A. Macmillan, M. K. Marina, and J. T. Triana, “Slow frequency hopping for mitigating tidal fading on rural long distance over-water wireless links,” in IEEE Conf. on Computer Communications (INFOCOM) Workshop, pp. 1– 5, IEEE, 2010.

[4] C.W. Ang and S. Wen. "Signal strength sensitivity and its effects on routing in maritime wireless networks." In *2008 33rd IEEE Conference on Local Computer Networks (LCN)*, pp. 192-199. IEEE, 2008.

[5] T. Rappaport, Wireless Communications: Principles and Practice. USA: Prentice Hall PTR, 2nd ed., 2002.

[6] M.G. Gaitan, P. M. Santos, L. Pinto and L. Almeida, “Wi-Fi-based network systems design over freshwater: Experimental evaluation using COTS devices,” in 15th Doctoral Symposium in Informatics Eng. (DSIE), 2020.

[7] M.G. Gaitan, P. M. Santos, L. Pinto and L. Almeida, “Experimental evaluation of the two-ray model for near-shore WiFi-based network systems design,” in 91st IEEE Vehicular Technology Conf. (VTC), 2020 (to appear).

[8] M.G. Gaitan, L. Pinto, P. M. Santos, and L. Almeida, “An Analysis of the Two-Ray Propagation Model to Support Near-Surface Overwater Wireless Sensor Networks Design,” in 3rd Doctoral Congress in Eng. (DCE), 2019.

[9] M.G. Gaitan, L. Pinto, P. M. Santos, and L. Almeida, “On the two-ray model analysis for overwater links with tidal variations,” in 2019 11th National Symposium on Informatics (INFORUM), 2019.

[10] F. Santos, L. Almeida, and L.S. Lopes. "Self-configuration of an Adaptive TDMA wireless communication protocol for teams of mobile robots." in IEEE Int. Conference on Emerging Technologies and Factory Automation (ETFA). IEEE, 2008.

[11] L. R. Pinto and L. Almeida. "A robust approach to TDMA synchronization in aerial networks." Sensors 18, no. 12 (2018): 4497.

[12] A. Aslam, L. Almeida, and F. Santos. "A flexible tdma overlay protocol for vehicles platooning." Int. Workshop on Communication Technologies for Vehicles. Springer, Cham, 2018.

[13] L. Oliveira, L. Almeida, and P. Lima. "Multi-hop routing within TDMA slots for teams of cooperating robots." 2015 IEEE World Conference on Factory Communication Systems (WFCS). IEEE, 2015.

[14] M.G. Gaitán and P.M. Yomsi. "FF-DBF-WIN: On the Forced-Forward Demand-Bound Function Analysis for Wireless Industrial Networks." Proceedings of the Work-in-Progress Session (ECRTS 2018) (2018): 13-15.

[15] M.G. Gaitán, P.M. Yomsi, P.M. Santos, and L. Almeida. "Work-in-Progress: Assessing supply/demand-bound based schedulability tests for wireless sensor-actuator networks." IEEE World Conf. on Factory Communication Systems (WFCS). IEEE, 2020 (to appear).

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